



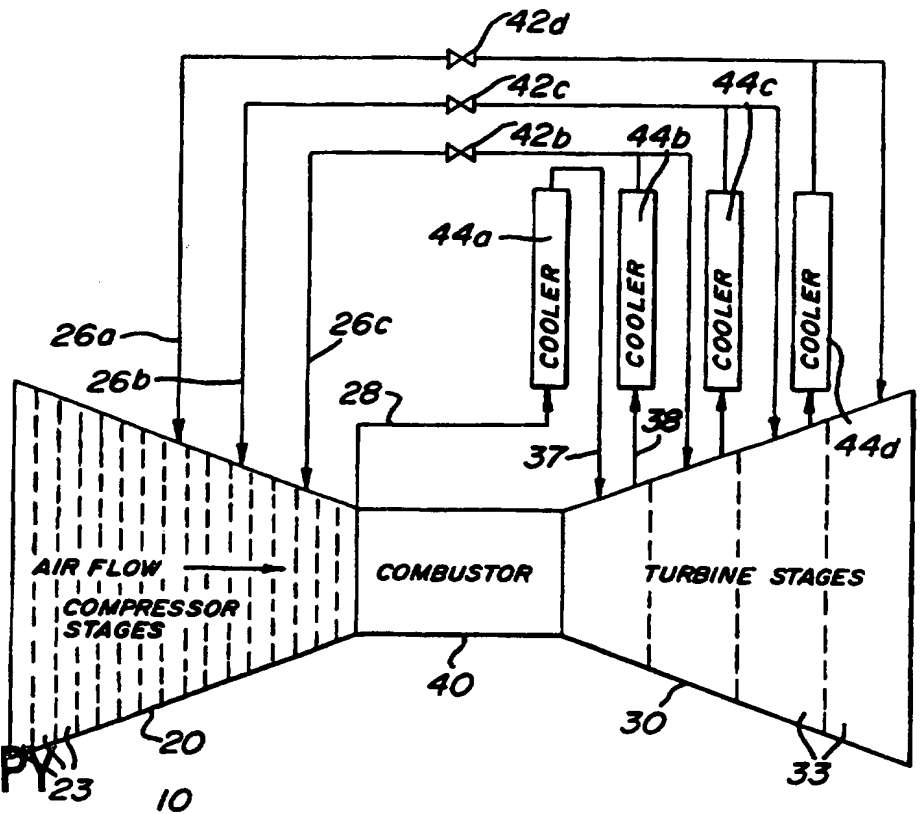
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : F02C 7/18, F01D 5/08		A1	(11) International Publication Number: WO 97/38219
			(43) International Publication Date: 16 October 1997 (16.10.97)
(21) International Application Number: PCT/US97/04484		(81) Designated States: CA, CN, JP, KR, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).	
(22) International Filing Date: 24 March 1997 (24.03.97)			
(30) Priority Data: 08/627,561 4 April 1996 (04.04.96) US		Published With international search report.	
(71) Applicant: WESTINGHOUSE ELECTRIC CORPORATION [US/US]; Westinghouse Building, Gateway Center, Pittsburgh, PA 15222 (US).			
(72) Inventor: NORTH, William, E.; 656 Cayuga Drive, Winter Springs, FL 32708 (US).			
(74) Agents: LENART, Robert, P. et al.; Westinghouse Electric Corporation, Westinghouse Building, Gateway Center, Pittsburgh, PA 15222 (US).			

(54) Title: CLOSED-LOOP AIR COOLING SYSTEM FOR A TURBINE ENGINE

(57) Abstract

Method and apparatus are disclosed for providing a closed-loop air cooling system for a turbine engine. The method and apparatus provide for bleeding pressurized air from a gas turbine engine compressor for use in cooling the turbine components. The compressed air is cascaded through the various stages of the turbine. At each stage a portion of the compressed air is returned to the compressor where useful work is recovered.



BEST AVAILABLE COPY

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon	KR	Republic of Korea	PL	Poland		
CN	China	KZ	Kazakhstan	PT	Portugal		
CU	Cuba	LC	Saint Lucia	RO	Romania		
CZ	Czech Republic	LI	Liechtenstein	RU	Russian Federation		
DE	Germany	LK	Sri Lanka	SD	Sudan		
DK	Denmark	LR	Liberia	SE	Sweden		
EE	Estonia			SG	Singapore		

CLOSED-LOOP AIR COOLING SYSTEM FOR A TURBINE ENGINE

Field of the Invention

The invention relates to cooling systems for use with turbine engines. More particularly, the invention relates to closed-loop cooling systems for returning air to the compressor cycle of a gas turbine engine after its use as a coolant in the combustion cycle.

Background of the Invention

Current gas turbine engines have peak temperatures in the combustor approaching 3000°F, yet alloys used to construct the turbine engines have melting points in the range of 2200 to 2400°F. Consequently, ample cooling of the turbine engine components is required. Both open-loop and closed loop cooling systems have been developed to provide turbine engine cooling needs.

Both types of systems commonly use pressurized air as a cooling medium. High pressure air provides better heat transfer characteristics than low pressure air as well as providing leakage or film cooling of turbine components. In open-loop cooling systems, spent cooling air passes through the cooled component and into the hot gas path. To pass out through the component, the cooling air must have sufficient pressure to overcome the pressure within the path. Additionally, the pressurization is required for leakage supply, so that air can escape from the component while

preventing the hot gas from entering the component. As a result of the need to overcome the surrounding pressure, components closer to the combustor, which experience higher pressures and hotter temperatures, require higher pressure cooling air. Conversely, components further from the combustor require less pressure.

According to conventional air cooling systems, the pressurized air requirements are met by bleeding air out of the compressor stages and feeding that air to the turbine stages. After use in cooling, the spent cooling air combines with the main turbine gas flow and exits the turbine through the exhaust system. To minimize the thermodynamic penalty, open-loop cooling systems remove the air from the lowest possible compression point. An exemplary turbine employing such an open loop system is described in Scalzo et al., *A New 150MW High Efficiency Heavy-Duty Combustion Turbine*, ASME Paper No.88-GT-162 (1988). Significantly, in open-loop air cooling systems, spent cooling air is bled into the gas path where it passes out of the turbine engine with the exhaust. Such a design is inefficient because the spent cooling air dilutes the main gas flow thus performing less useful work than it would have had it been heated in the combustion process.

Closed-loop cooling systems have been proposed that use an external compressor to provide the necessary pressure to circulate the coolant and to generate the required heat transfer characteristics. In such a system, air circulates out of the turbine after providing the cooling and is re-compressed before being injected directly into the combustor. However, this type of closed-loop cooling system requires expensive external compressors. Applicants have recognized that more efficiency can be gained if the external compressors can be eliminated.

Thus, there is a need for a closed-loop cooling system for use in a turbine engine that recovers the compressed air after it has been used in cooling without the need for external compressors.

Summary of the Invention

The present invention meets the needs above by providing closed-loop air cooling to each turbine stage by bleeding pressurized air from the compressor and providing the
5 air to the turbine. After the pressurized air has removed heat from each turbine stage, it is routed out and cooled to a predetermined temperature. Next, a first portion of the pressurized air is routed into the next stage of the turbine. A second portion of the pressurized air is routed back to the
10 compressor. This procedure is repeated for each turbine stage.

Brief Description of the Drawings

The foregoing summary, as well as the following detailed description of the preferred embodiment, is better
15 understood when read in conjunction with the appended drawings. For the purpose of illustrating the invention, there is shown in the drawings an embodiment that is presently preferred, it being understood, however, that the invention is not limited to the specific methods and instrumentalities
20 disclosed.

In the drawings:

FIGURE 1 is a schematic depiction of a gas turbine engine using a closed-loop system in accordance with the present invention;

25 FIGURE 2 is a sectional view of a cooling circuit through the turbine stages of the turbine engine.

FIGURE 3 is a sectional view of the injection path of the spent cooling air into the compressor stages.

Detailed Description of a Preferred Embodiment

Referring now to the drawings wherein like numerals indicate like elements throughout, FIGURE 1 presents a diagram of an exemplary turbine engine 10 employing a closed-loop cooling system according to the present invention. Significantly, the present invention could be adapted to a turbine engine 10 with any number of compressor and turbine stages. However, for purposes of illustration, FIGURE 1 demonstrates the present invention adapted for use in a turbine engine 10 having sixteen compressor stages 23 and four turbine stages 33. For clarity, each compressor and turbine stage is depicted in FIGURE 1 as a set of dashed lines. As is better depicted in FIGURES 2 and 3, each compressor stage 23 and turbine stage 33 comprises a set of vanes 21, 31 and blades 22, 32.

As in all conventional turbine engines, air flows axially through the turbine engine 10 depicted in FIGURE 1. Initially, the air flows in through the multiple stages of the compressor 20, with each stage further compressing the air. After the final compressor stage 23, the air reaches the compressor discharge point. There, the compressed air enters the combustor 40 and mixes with fuel. The air and fuel mixture is then fired and expands outward through the multiple stages of the turbine 30. The hot gas expanding out through the turbine 30 generates intense heat in the components (e.g., vanes and blades) in the gas path.

According to an aspect of the present invention, a more efficient cooling system is attained by bleeding air out of the compressor 20 before it reaches the combustor 40, using that bleed air to cool the components within the turbine 30 and then returning the bleed air to the compressor 20. According to the presently preferred embodiment, the air is bled from the compressor 20 at the discharge point, i.e., just before entry into the combustor 40. Before use in cooling, this compressor discharge air is directed out of the turbine engine 10, cooled and filtered. Then, it is returned to the turbine engine 10 to be cascaded through each of the four

- 5 -

stages in the turbine 30. During the cascading through the stages of the turbine 30, the air enters each stage, removes heat from components then exits, where the pressurized air is once again cooled before cascading to the next stage of the turbine 30. After each stage, a portion of the pressurized air is returned to the compressor 20 and a portion of the pressurized air advances to the next stage. Each subsequent stage of the turbine 30 demands less pressure than the previous stage as the pressure and temperature decreases within each stage. To maximize air pressure recovery and, thus efficiency, the pressure demands flowing to the next stage of the turbine 30 are regulated such that substantially the minimal necessary pressure is provided. Excess pressurized air is returned to the compressor 20, where useful energy is recovered.

Further details of the current invention will now be described with respect to an exemplary turbine engine 10. Those details are for illustration purposes only, as the present invention is equally applicable to other turbine engines. Thus, all references to temperatures, pressures, stages and the like will vary according to the specifics of a particular turbine engine.

As described above, the turbine engine 10 depicted in FIGURE 1 comprises sixteen compressor stages 23. According to the presently preferred embodiment, after intake air has passed sixteen compressor stages, a portion of the compressed air will be bled out at the compressor discharge point as indicated by line 28. This pressurized air will have a predetermined pressure (e.g., 350 PSI) and temperature (e.g., 1000°F). To enhance the pressurized air's cooling capability, it is routed through cooler 44a. Note that cooler 44a is optional. It is possible to cool the stage one turbine without the cooler 44a. However, the subsequent coolers 44 are required. The air exiting cooler 44a has a desired temperature, e.g., approximately 300°F, determined to provide satisfactory cooling of the turbine components. Similarly, at each subsequent stage of turbine cooling, the air is

similarly routed through a cooler 44. The coolers 44 are of a type well-known in the art, such as air-to-air, air-to-steam or air-water. Therefore, the details of such coolers 44 are left out of the present description for brevity and clarity.

5 The air exiting the first cooler 44a is routed via line 37 into the first stage of turbine 30, where it enters the turbine cooling circuit illustrated in FIGURE 2. The section of turbine 30 shown has four turbine stages 33. Following the flow of cooling air through the cooling circuit, 10 the cooling air first enters the turbine 30 at stage one via conduit 37a. The cooling air then enters the manifold via an air inlet and flows through the manifold 36 and into the first stage components, e.g., vane 31. Heat is removed from the components according to well-known techniques such as 15 impingement or internal convection cooling. Significantly, the air flows into and out of the components then travels back through the manifold 36 and out via an air outlet in flow communication with conduit 38a. After the air has exited stage one of the turbine 30, it flows through cooler 44b 20 before use in the next stage of the turbine 30.

After the air exits cooler 44, a portion of the pressurized air will flow on to the next stage of the turbine 30. However, according to the present invention, subsequent stages may not require all of the pressurized air exiting the 25 previous stages. Thus, a portion of the air is shunted back to the compressor 20. The shunting of air back to the compressor 20 is regulated by control valve 42.

According to the presently preferred embodiments, control valve 42 may be either pressure or temperature 30 sensitive. In the case of pressure sensitivity, the valve 42 will regulate the pressure in the next turbine stage 33 to maintain a predetermined level. Any remaining air will be allowed to flow through the valve 42 and will be injected back into the compressor 20. Thus, the control valve 42 will 35 properly react to changing ambient conditions, such as changes in ambient temperature and pressure, to maintain the required pressure within the turbine cooling circuit.

Alternatively, the control valve 42 may be temperature sensitive. In such a case, a thermocouple (not shown) embedded in the next turbine stage 33 will provide temperature information to the control valve. As a result, the control valve 42 will adjust the pressure accordingly to maintain a preset temperature.

As noted above, each subsequent stage of turbine 30, requires less pressure than the preceding stage. Consequently, the pressure of the air returned to the compressor 20 continually decreases and must be injected into the compressor 20 at different stages. For example, the air pressure returned to the compressor via valve 42b may be approximately 200 PSI, while the air pressure returned to the compressor 20 via valve 42c will be approximately 125 PSI, and the air pressure returned via valve 42d will be approximately 75 PSI. Thus, as best illustrated in FIGURE 1, return air from stage one of the turbine 30 flows to stage fourteen in the compressor 20, stage two of the turbine 30 flows to stage eleven in the compressor 20 and stage three of the turbine 30 flows to stage eight of the compressor 20.

FIGURE 3 illustrates the presently preferred embodiment for the injection circuit of return air into the compressor 20. As shown, manifold 24 surrounds the compressor 20. Return air flows into the manifold 24 which is connected to conduits 26 via air inlets. For example, conduit 26a carries the airflow from stage three of turbine 30 into stage eight of the compressor 20. The injection stage will be selected such that the return air will have a pressure that substantially corresponds to the pressure of within the stage of the compressor 20 wherein it is injected. The return air will then combine with the air flow path through the compressor 20 and complete the turbine cycle.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof; for example, a similar technique could be utilized to provide cooling to the blades rather than the vanes as depicted in the FIGURES. Accordingly, reference

should be made to the appended claims, rather than to the foregoing specification, as indicating the scope of the invention.

- 9 -

WHAT I CLAIM IS:

1. In a turbine engine having a compressor and a turbine, an apparatus for cooling the turbine, comprising:
first means in flow communication between the compressor and the turbine for bleeding pressurized air from
5 the compressor into the turbine;
second means in flow communication between the turbine and the compressor for returning at least a portion of said pressurized air back to the compressor.
2. The apparatus as recited in claim 1 further
10 comprising third means disposed between the compressor and the turbine for cooling pressurized air to a predetermined temperature.
3. The apparatus as recited in claim 1, wherein said turbine comprises at least two turbine stages, further
15 comprising fourth means in flow communication between said at least two turbine stages for providing at least a portion of said pressurized air from one of said at least two turbine stages to another one of said at least two turbine stages.
- 20 4. The apparatus as recited in claim 3 further comprising cooling means disposed within said fourth means.
5. The apparatus as recited in claim 4 wherein said cooling means comprises one of an air-to-air cooler, an air-to-steam cooler, and an air-to-water cooler.

6. The apparatus as recited in claim 3 further comprising a control valve for portioning the pressurized air such that a second portion of said pressurized air returns to the compressor.

5 7. In a gas turbine engine having a compressor and a turbine with a cooling circuit, a closed-loop cooling system for the turbine, comprising:

a first compressor cooling air outlet in flow communication with pressurized air generated by the
10 compressor;

a first turbine cooling circuit inlet in flow communication with the cooling circuit within the turbine;

a first conduit in flow communication between said first compressor cooling air outlet and said first turbine
15 cooling circuit inlet such that pressurized air is supplied to the turbine from the compressor;

a first turbine cooling circuit outlet in flow communication with the cooling circuit within the turbine;

a first compressor return air inlet in flow
20 communication with the pressurized air within the compressor; and,

a second conduit in flow communication between said first turbine cooling circuit outlet and said first turbine cooling circuit inlet such that at least a first portion of
25 said pressurized air is returned to the compressor from the turbine.

8. The apparatus as recited in claim 7 further comprising a cooler disposed along said first conduit such that said pressurized air is cooled to a predetermined
30 temperature before entering the cooling circuit within the turbine.

9. The apparatus as recited in claim 8 wherein said cooler comprises one of an air-to-air cooler, an air-to-
35 steam cooler, and an air-to-water cooler.

- 11 -

10. The apparatus as recited in claim 6, wherein the turbine has at least two stages each stage having a cooling circuit and wherein said first turbine cooling circuit outlet is coupled to one of the stages of the turbine, further
5 comprising:

a second turbine cooling circuit inlet in flow communication with the cooling within an other one of the stages of the turbine;

a conduit coupled between said first turbine cooling
10 circuit outlet and said second turbine cooling circuit inlet such that a second portion of pressurized air flows out of said one of the stages of the turbine and into an other one of said stages of the turbine.

11. The apparatus as recited in claim 10 further
15 comprising a second cooler disposed between said one of the stages of the turbine and said other one of the stages of the turbine such that said portion of pressurized air is cooled to a predetermined temperature before flowing into said an other one of said stages of the turbine.

12. The apparatus as recited in claim 7 further
20 comprising a control valve disposed between said turbine and said compressor such that the amount of pressurized air in said first portion and said second portion is regulated.

13. In a gas turbine engine having at least two
25 compressor stages and at least two turbine stages wherein each turbine stage has a plurality of vanes, a method for providing closed-loop air cooling to the plurality of vanes in each of the turbine stages, comprising:

bleeding pressurized air from one of the compressor
30 stages for use in cooling the turbine;

routing said pressurized air into the plurality of vanes in one of the turbine stages;

routing said pressurized air out of the plurality of vanes after said pressurized air has removed heat from the vanes

routing a first portion of said pressurized air into
5 the plurality of vanes in an other one of the turbine stages;
and,

returning a second portion of said pressurized air back to the compressor at an other one of said compressor stages.

10 14. The method as recited in claim 13 further comprising the step of cooling pressurized air to a predetermined temperature after said bleeding step.

15 15. The method as recited in claim 13 wherein said means for routing comprises a conduit.

16 16. The method as recited in claim 15 wherein said means for cooling comprises one of an air-to-air cooler, an air-to-steam cooler, and an air-to-water cooler.

17. The method as recited in claim 16 wherein said means for bleeding air comprises a manifold coupled to a
20 discharge end of the compressor.

18. In a gas turbine engine having at least two compressor stages and at least two turbine stages wherein each turbine stage has a plurality of vanes, a method for providing closed-loop air cooling to the plurality of vanes in each
25 turbine stage, comprising:

bleeding pressurized air from one of the compressor stages into the plurality of vanes in one of the at least two turbine stages;

routing said pressurized air out of the plurality
30 of vanes after said pressurized air has removed heat from the vanes

cooling said pressurized air to substantially a predetermined temperature;

routing a first portion of said pressurized air into the plurality of vanes in an other one of the at least two
5 turbine stages; and,

returning a second portion of said pressurized air back to the compressor at an other one of said at least two compressor stages.

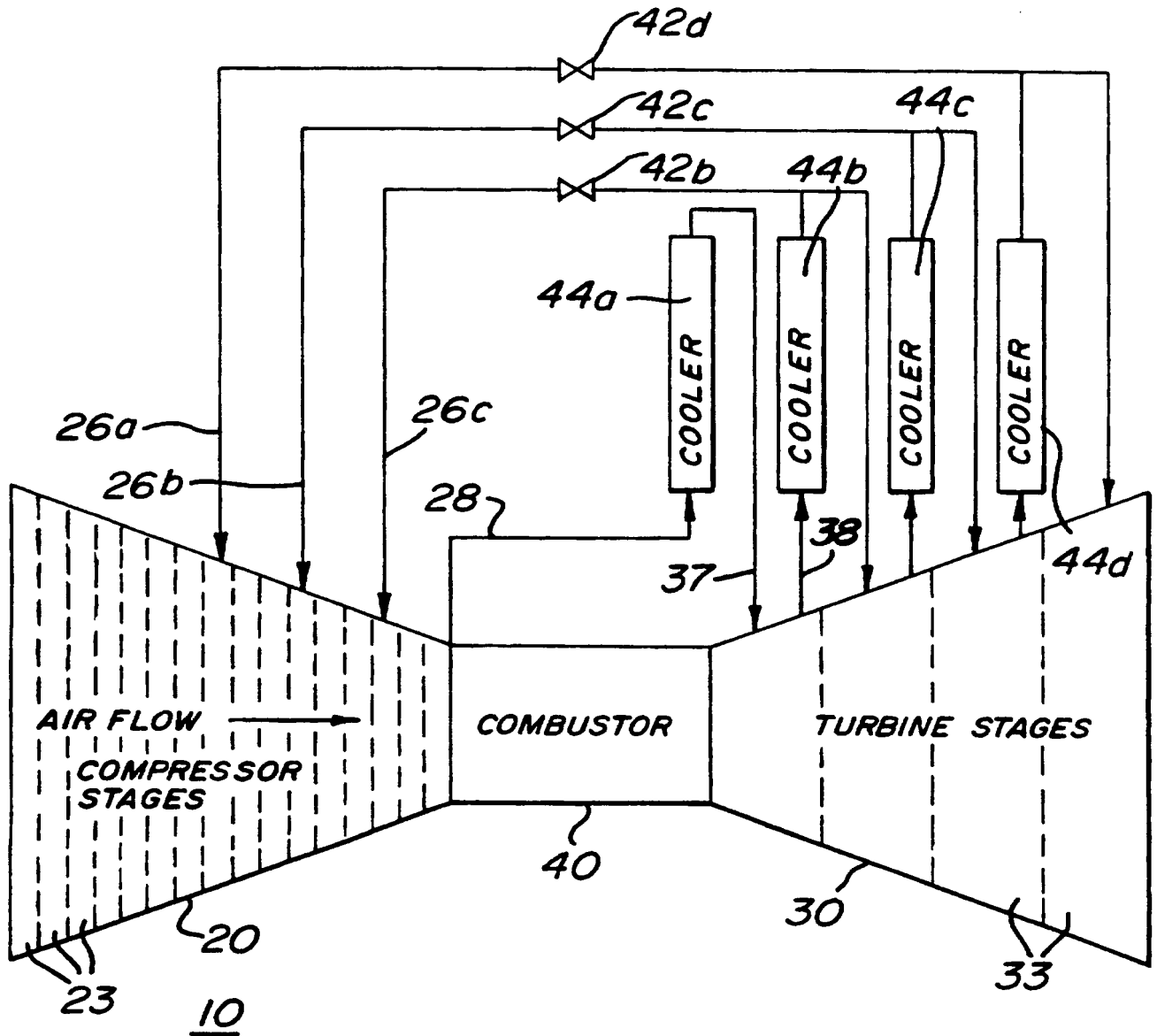


FIG. 1

FIG. 2

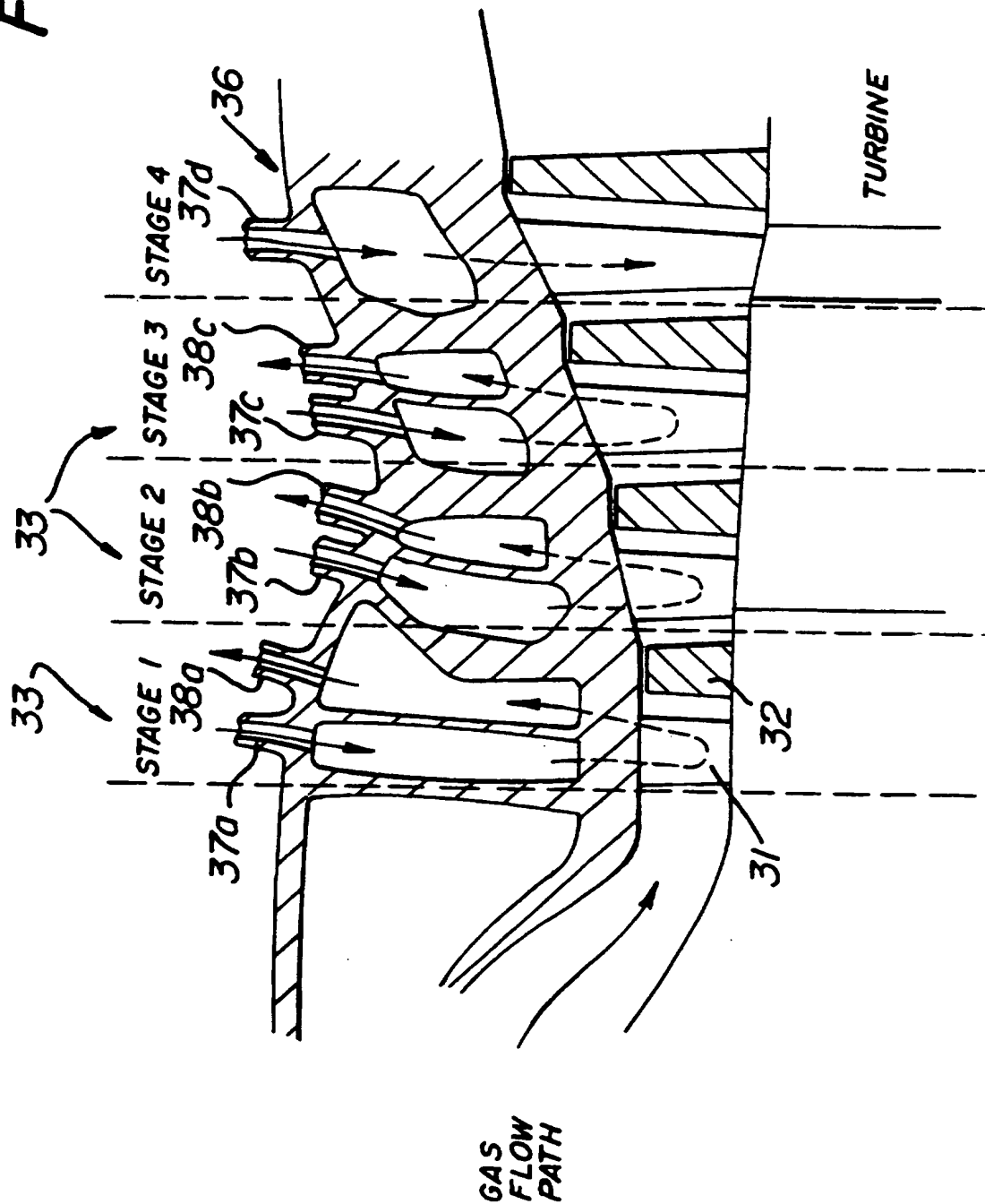
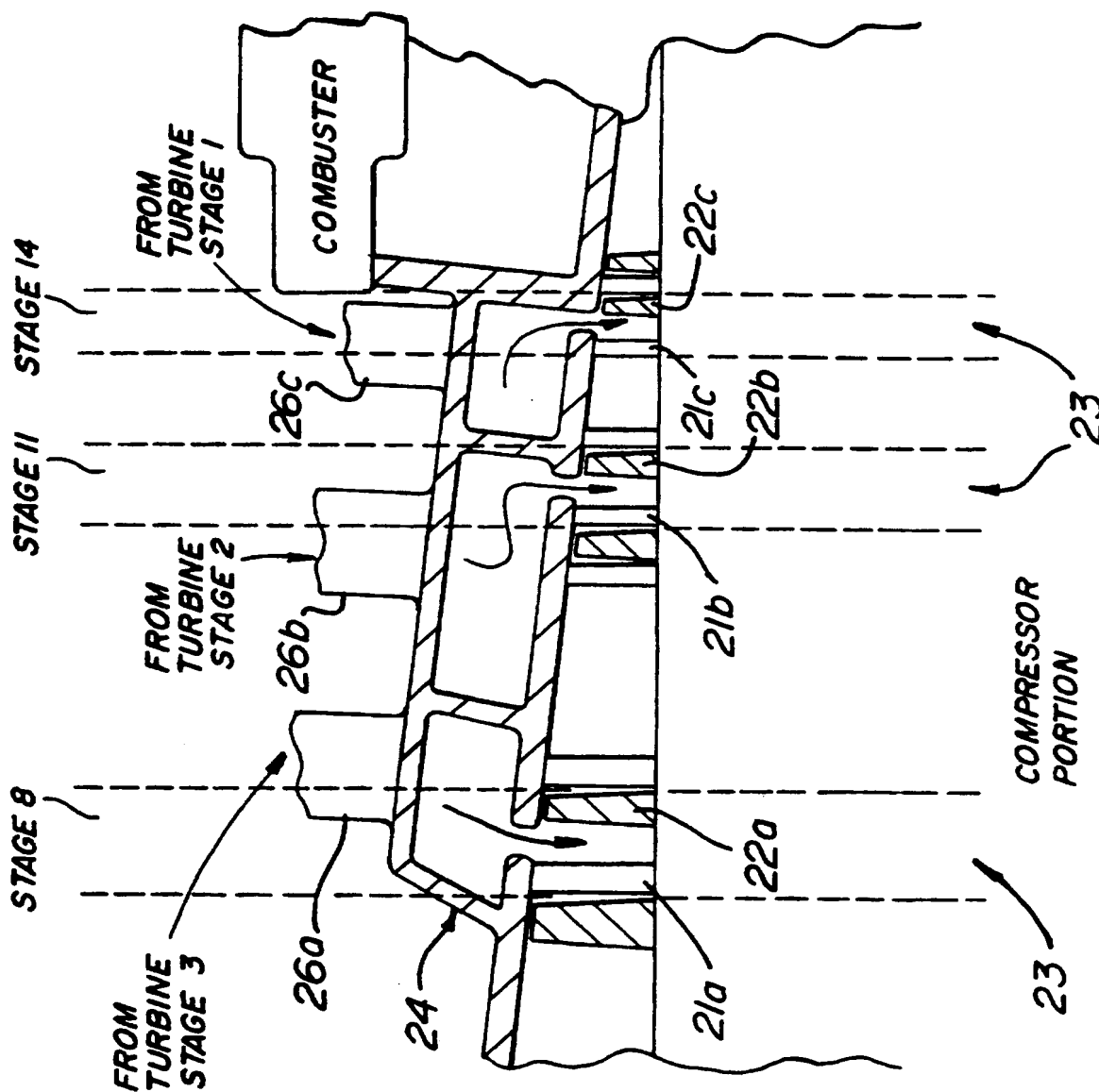


FIG. 3



INTERNATIONAL SEARCH REPORT

Intern. Application No
PCT/US 97/04484

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 F02C7/18 F01D5/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 F02C F01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	US 5 611 197 A (BUNKER RONALD S) 18 March 1997 see the whole document ---	1,3,7, 10,13, 15,18
A	US 2 940 257 A (ECKERT) 14 June 1960 see column 3, line 30 - column 8, line 57; figures 1-5 ---	1-3, 6-10, 12-18
A	US 5 394 687 A (CHEN ALLEN G ET AL) 7 March 1995 see the whole document ---	1,7,13, 18
A	US 2 445 837 A (MCKENZIE) 27 July 1948 see the whole document ---	1,7,13, 18
-/--		

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *&* document member of the same patent family

Date of the actual completion of the international search

16 July 1997

Date of mailing of the international search report

25. 07. 97

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl,
Fax (+ 31-70) 340-3016

Authorized officer

Iverus, D

INTERNATIONAL SEARCH REPORT

Intern. Application No
PCT/US 97/04484

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2 618 120 A (PAPINI) 18 November 1952	1-3, 6-10, 12-18
	see the whole document	
A	US 2 654 220 A (BOESTAD) 6 October 1953	

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inten. nal Application No

PCT/US 97/04484

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5611197 A	18-03-97	NONE	
US 2940257 A	14-06-60	DE 948929 C FR 1097374 A GB 751884 A GB 754856 A	05-07-55
US 5394687 A	07-03-95	EP 0656468 A JP 7189738 A	07-06-95 28-07-95
US 2445837 A	27-07-48	NONE	
US 2618120 A	18-11-52	NONE	
US 2654220 A	06-10-53	NONE	

THIS PAGE BLANK (USPTO)

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ **BLACK BORDERS**
- ☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- ☐ **FADED TEXT OR DRAWING**
- ☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- ☐ **SKEWED/SLANTED IMAGES**
- ☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- ☐ **GRAY SCALE DOCUMENTS**
- ☒ **LINES OR MARKS ON ORIGINAL DOCUMENT**
- ☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- ☐ **OTHER:** _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.

THIS PAGE BLANK (USPTO)